

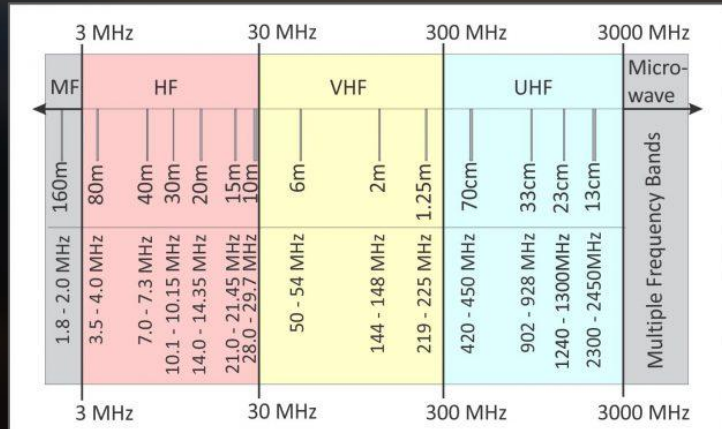
Doublet Antenna

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ENGR 473 W2025

Introduction

- I am an Amateur Radio Operator. Callsign, VE7KWZ.
- This project topic is about an antenna I built for my HF radio setup.



Preface

- Building a new antenna further away from the house requires more transmission line.
- I only have about 100 ft of coaxial cable, and it's fairly expensive.
- Open-wire transmission lines are easy to make.
- **Why not make a doublet!**



Doublet Antenna

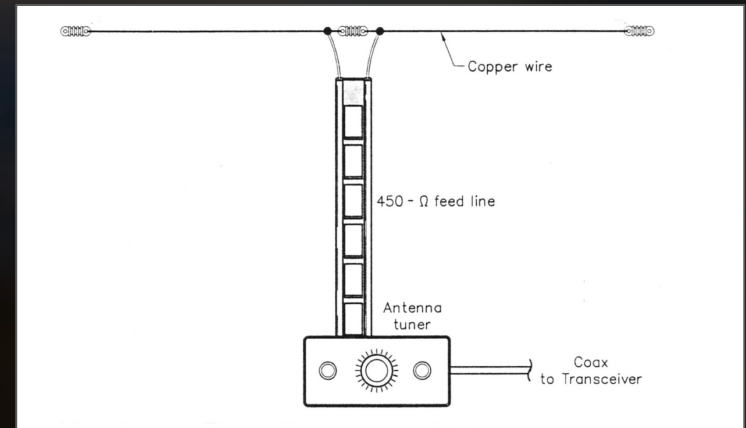
- Why is this antenna used among amateur radio operators?
 - Simple construction
 - Cheap to make
 - Efficient over multiple frequency bands



Doublet Antenna

- The doublet is a dipole antenna, but operated outside of its resonant mode.
- This means there exists very high VSWR!
- Because of that, there is one caveat...

The antenna must be tuned using an antenna tuner for efficient multi-band operation.

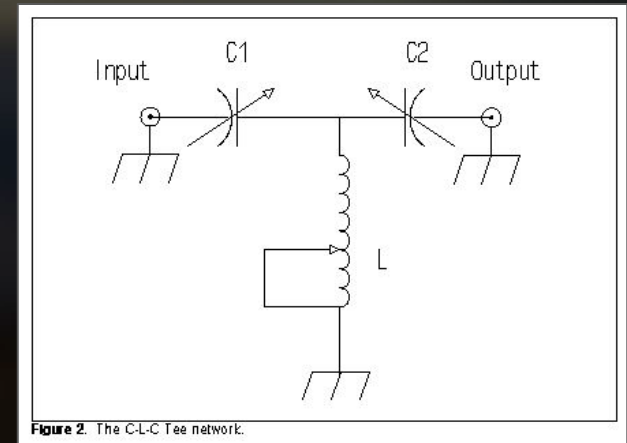


Antenna Tuners

- Variable/adjustable impedance matching network
- Wide matching range (typ. $6\ \Omega$ to $1600\ \Omega$)
- Matches *almost* any antenna to a $50\ \Omega$ system
- Tuners can be manual or automatic

A good reference on matching network architectures:

[SiLabs AN1275 Impedance Matching Networks](#)



Feedline

- The feedline to a doublet is balanced, and usually an open-wire “ladder” transmission line.
- The transmission line will typically have a characteristic impedance of 450 Ω , but 300 Ω and 600 Ω have been used as well.
- Doublets can experience a VSWR upwards of 50:1 and still be operable (*efficiently*)!



Feedline

- The two-wire feedline is very low loss which gives the antenna its efficiency under poor matching conditions.

4x lower loss than the LMR-400 coax I currently use

approx. 0.005 dB/m at 14 MHz

approx. 0.020 dB/m at 14 MHz

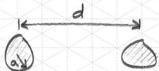
Two-Wire Transmission Line

$$C' = \frac{\epsilon \pi}{\ln(d/a)} \left[\frac{\text{Farad}}{\text{m}} \right], L' = \frac{\mu}{\pi} \ln(d/a) \left[\frac{\text{henry}}{\text{m}} \right]$$

$$R' = \frac{1}{\sigma \pi a} \left[\frac{\text{ohm}}{\text{m}} \right], Z_0 \approx \sqrt{\frac{L'}{C'}} \left[\text{ohm} \right]$$

$a = 0.65 \text{ mm}$
 $d = 28 \text{ mm}$
 $\epsilon = 5.69 \times 10^7 \text{ } \epsilon_m$
 $\sigma = 17.83 \times 10^{-6} \text{ m}$

$C' = 7.39 \text{ [PF/m]}$
 $L' = 1.51 \text{ [}\mu\text{H/m]}$
 $R' = 0.483 \text{ [}\Omega\text{/m]}$
 $Z_0 = 452 \text{ [}\Omega\text{]}$



Loss: $8.686 \cdot \frac{R'}{Z_0} \Rightarrow \underline{0.0047 \text{ [dB/m]}}$

LMR[®]-400 Flexible Low Loss Communications Coax

Ideal for...

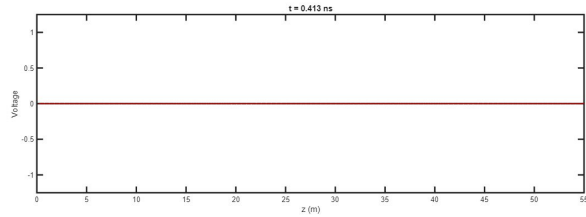
- Drop-in replacement for RG-8/9913 Air-Dielectric type Cable
- Jumper Assemblies in Wireless Communications Systems
- Short Antenna Feeder runs
- Any application (e.g. WLL, GPS, LMR, WLAN, WISP, WiMax, SCADA, Mobile Antennas) requiring an easily routed, low loss RF cable
- **NEW!** Times Protect[®] LP-18-400 protector-series



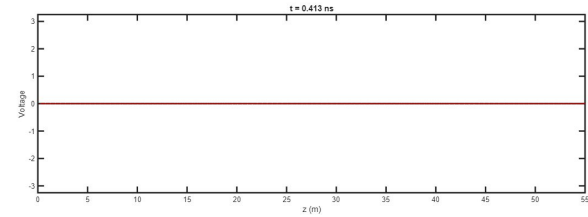
Frequency (MHz)	30	50	150	220	450	900
Attenuation dB/100 ft	0.7	0.9	1.5	1.9	2.7	3.9
Attenuation dB/100 m	2.2	2.9	5.0	6.1	8.9	12.8

Feedline

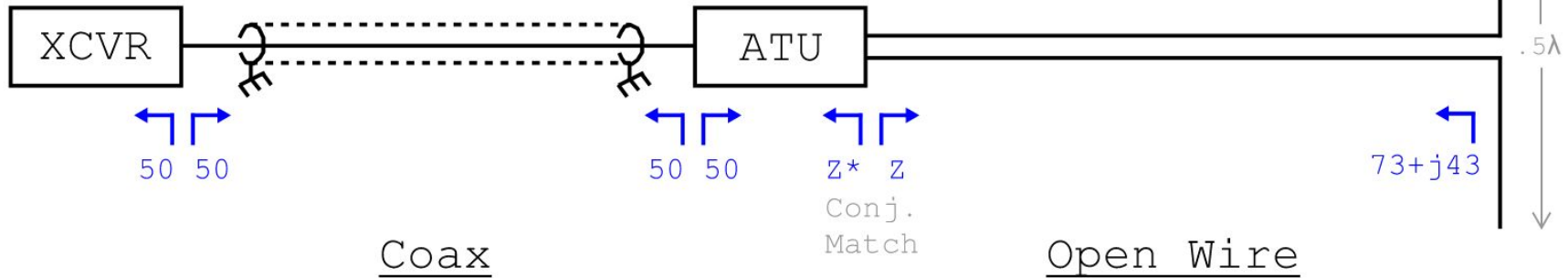
➤ Now, what happens at each stage...



VSWR = 1



VSWR \gg 1



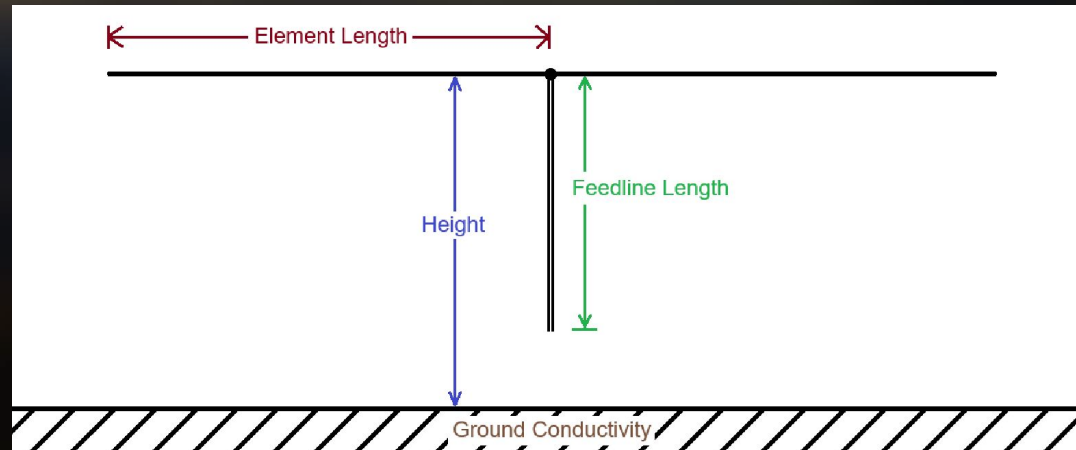
Simulation

- Because of dimension limitations within AWR AXIEM, the operating frequency of the simulated antenna was set to be between 500 MHz and 3000 MHz.
- Most characteristics of the antenna will scale with wavelength, but the conductor loss will be greater than it would be at HF bands (3-30 MHz) due to skin depth.

Simulation Roadmap

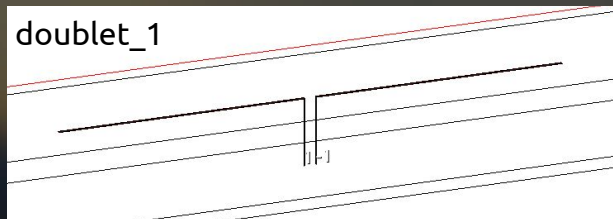
What was simulated:

- Feedline models/orientation in AWR
- Feedline length
- Height off ground
- Earth Conductivity



Feedline Model

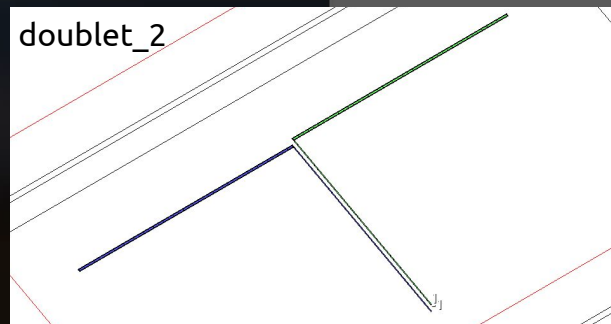
- Both horizontal and vertical feedline orientations were simulated.



Note: doublet_2 feedline visually scaled

Due to the scaled/miniaturized nature of the two-wire via feedline, skin effect resistances and small conductor cross section caused greater loss.

The horizontal feedline was chosen as it presented a lower loss, which is also closer to realized values.



Feedline Model

◆ Efficiency(1) Rad. Efficiency
doublet_1.@doublet_via_2wire

▣ Efficiency(1) Rad. Efficiency
doublet_2.@doublet_strip_feedline

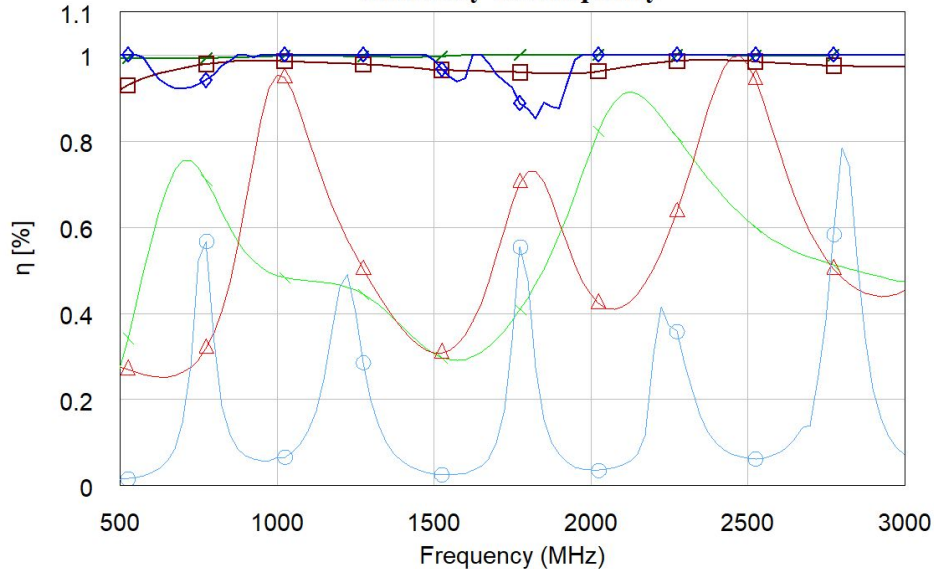
◆ Efficiency(1) Rad. Efficiency
dipole.@dipole_nofeed

○ Efficiency(2) Match Efficiency
doublet_1.@doublet_via_2wire

△ Efficiency(2) Match Efficiency
doublet_2.@doublet_strip_feedline

◆ Efficiency(2) Match Efficiency
dipole.@dipole_nofeed

Efficiency vs. Frequency

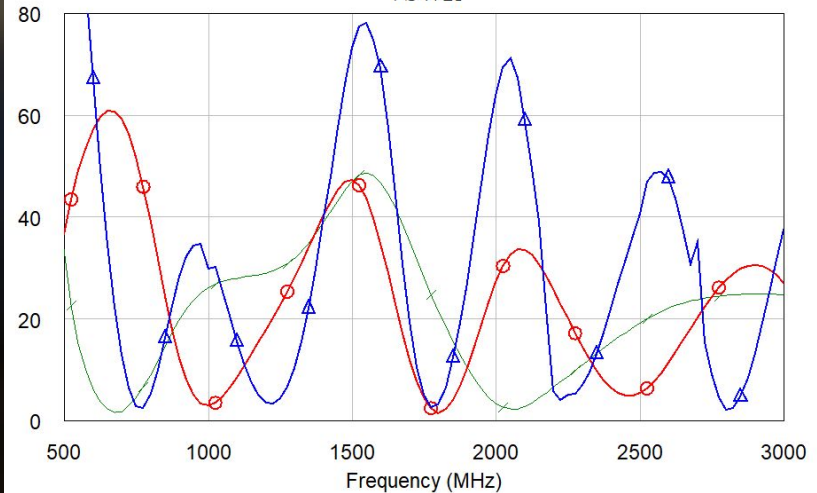


▲ VSWR(1)
doublet_1.@doublet_via_2wire

○ VSWR(1)
doublet_2.@doublet_strip_feedline

◆ VSWR(1)
dipole.@dipole_nofeed

VSWR



Feedline Length

➤ Feedlines that are,

combinations of feedline electrical length plus the length of one element being an odd integer multiple of $\lambda/8$ (eg $\lambda/4 + \lambda/8 = 3\lambda/8$),

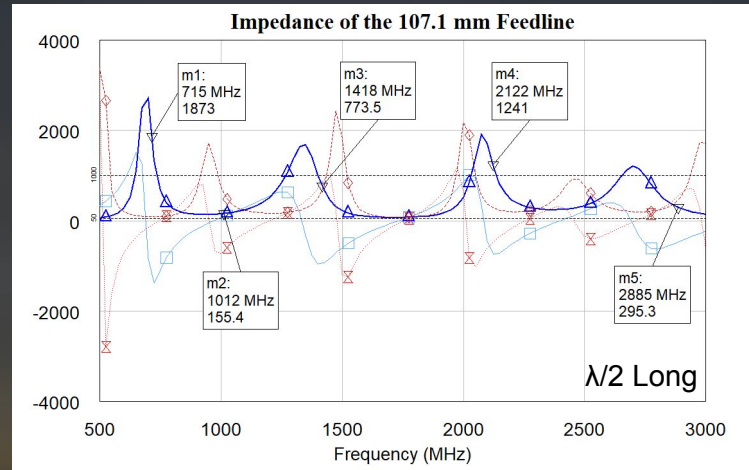
or integers multiples of $\lambda/2$'s long,

➤ created impedances that were difficult (*but not impossible*) to match to.

		N	3	4	5	7	8	9	11	12	13	15
Frequency (MHz)	λ (m)	Element (m)	0.375λ (m)	0.5λ (m)	0.625λ (m)	0.875λ (m)	1λ (m)	1.125λ (m)	1.375λ (m)	1.5λ (m)	1.625λ (m)	1.875λ (m)
7.00	42.86	10.71	16.07	21.43	26.79	37.50	42.86	48.21	58.93	64.29	69.64	80.36
TLINE Lengths (m) to avoid:			5.36	10.71	16.07	26.79	32.14	37.50	48.21	53.57	58.93	69.64

Lengths are multiplied by 0.01 for the simulation model

Feedline Length

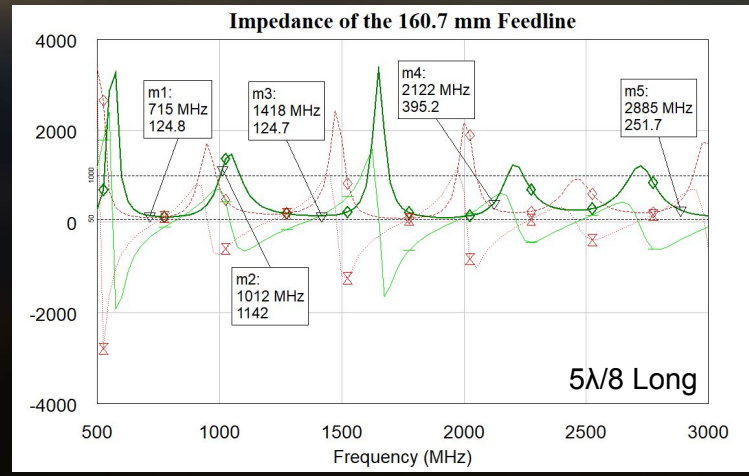
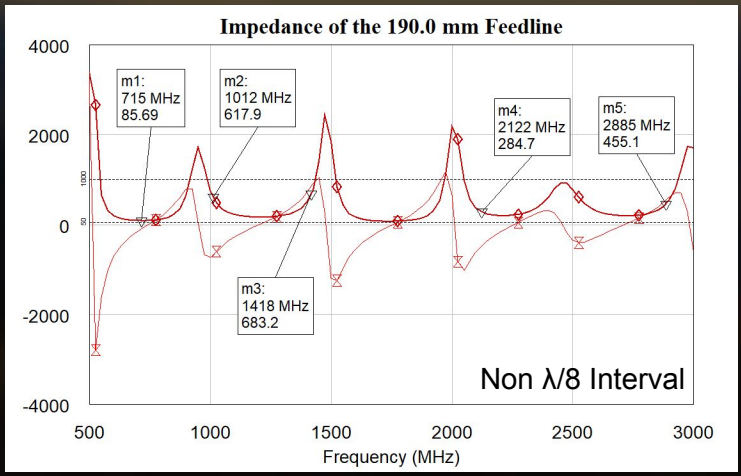


◇ Re(Z(1,1))
doublet_2.@190mm_feed

⊗ Im(Z(1,1))
doublet_2.@190mm_feed

▲ Re(Z(1,1))
doublet_2.@107mm_feed

□ Im(Z(1,1))
doublet_2.@107mm_feed



◇ Re(Z(1,1))
doublet_2.@160mm_feed

— Im(Z(1,1))
doublet_2.@160mm_feed

Feedline Length

—x— Efficiency(1) Radiated
doublet_2.@190mm_feed

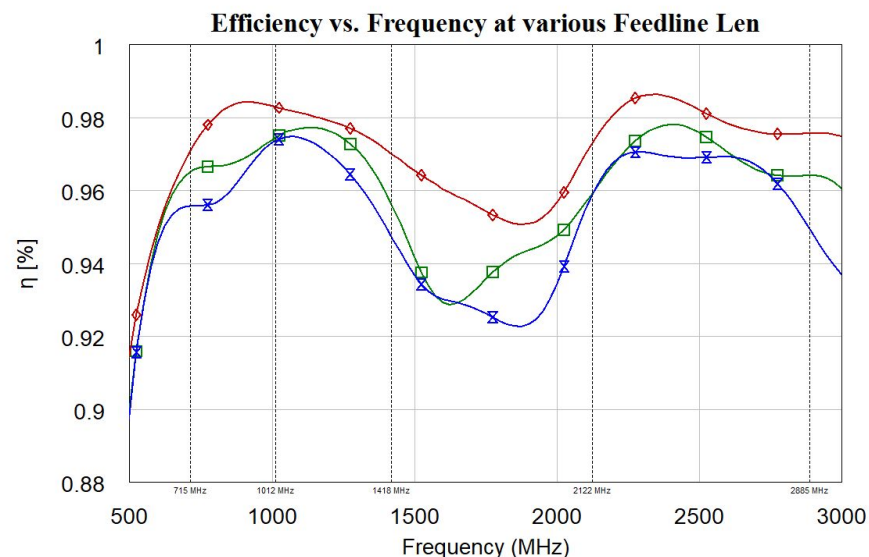
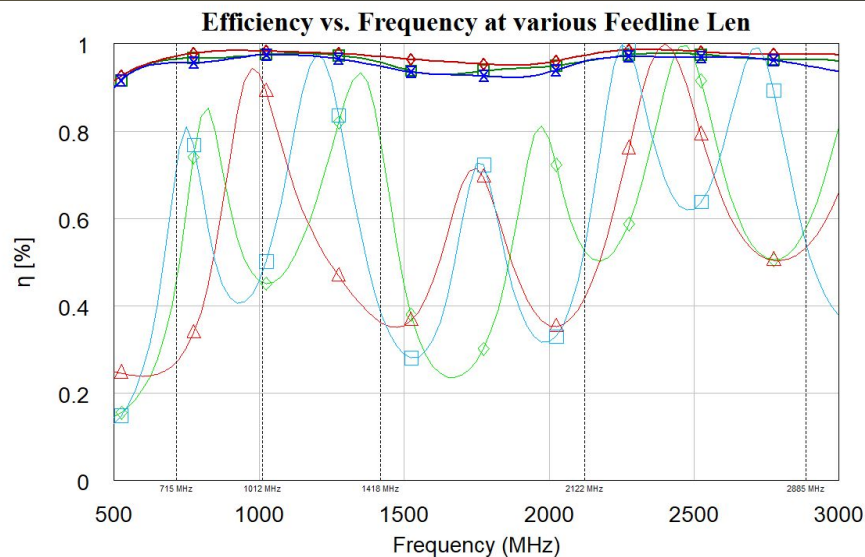
—◇— Efficiency(1) Radiated
doublet_2.@107mm_feed

—□— Efficiency(1) Radiated
doublet_2.@160mm_feed

—□— Efficiency(2) Matching
doublet_2.@190mm_feed

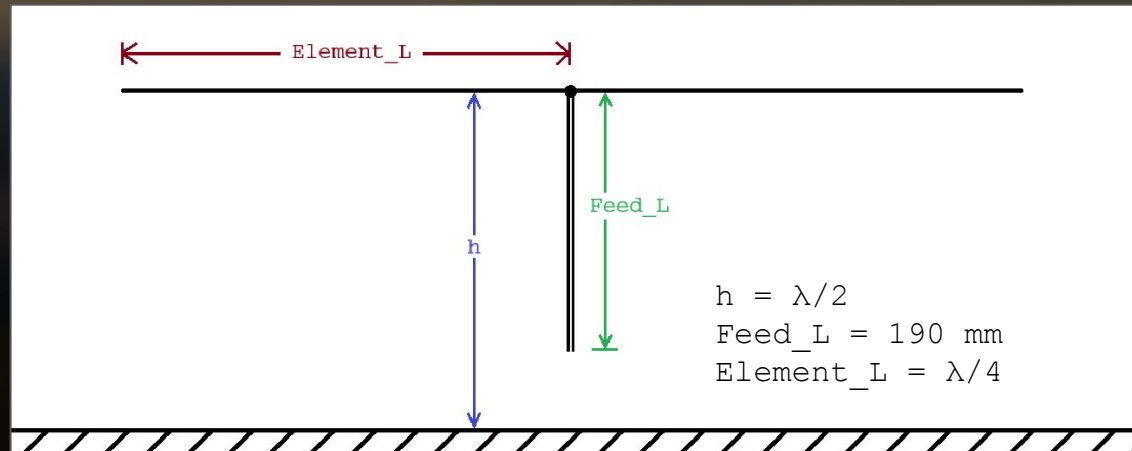
—△— Efficiency(2) Matching
doublet_2.@107mm_feed

—◇— Efficiency(2) Matching
doublet_2.@160mm_feed

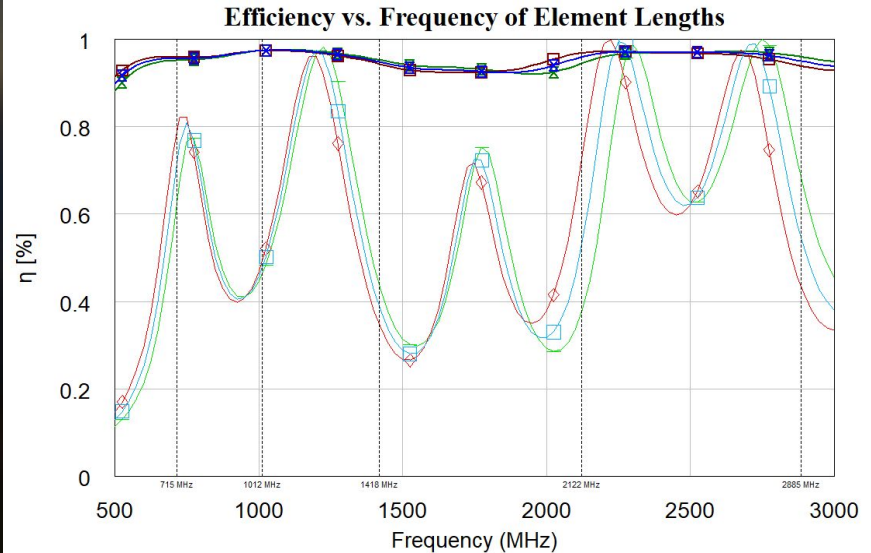
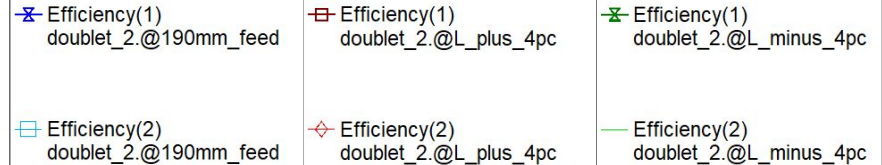
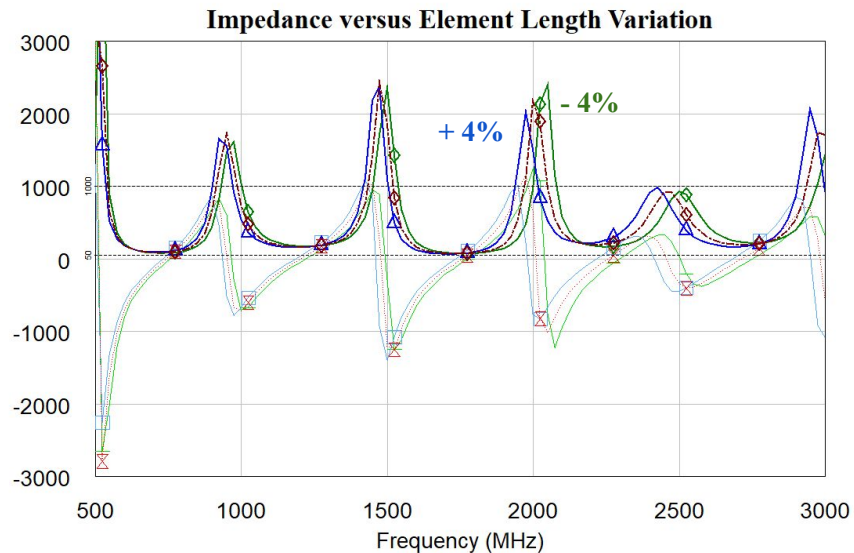
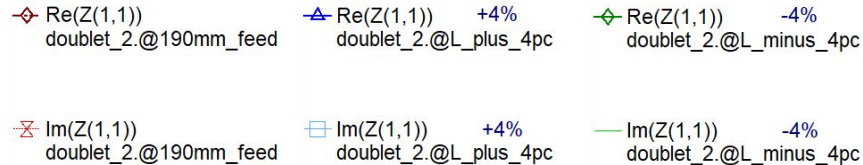


Element Length

- The length of the doublet is typically a half-wavelength of its lowest operating frequency -- Meaning each element is $\lambda/4$ long when center-fed.

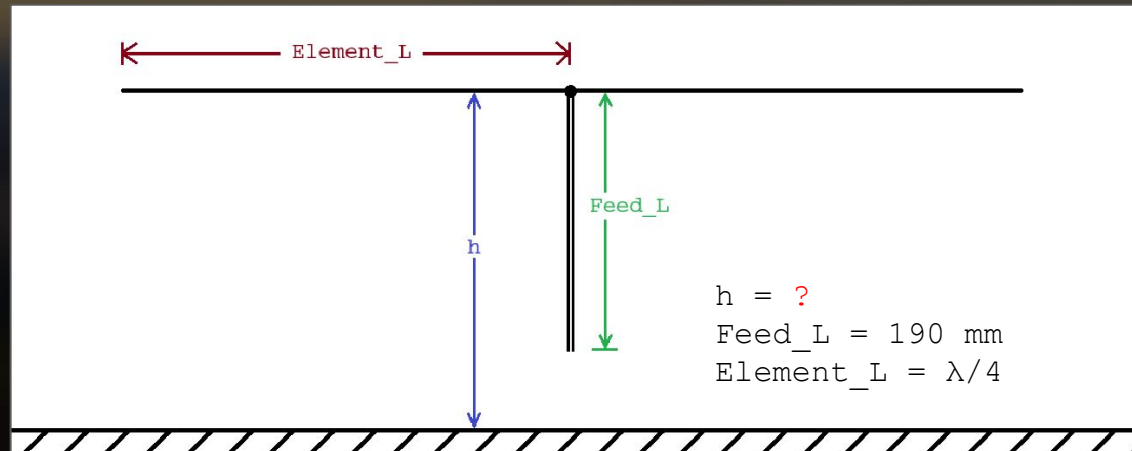


Element Length



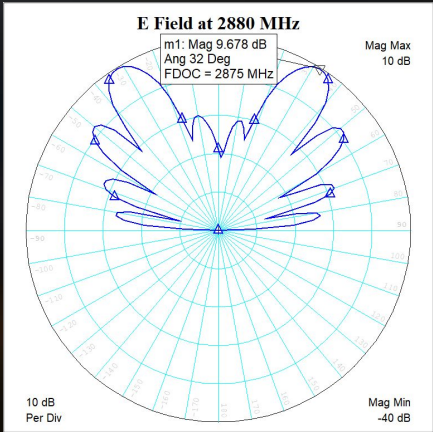
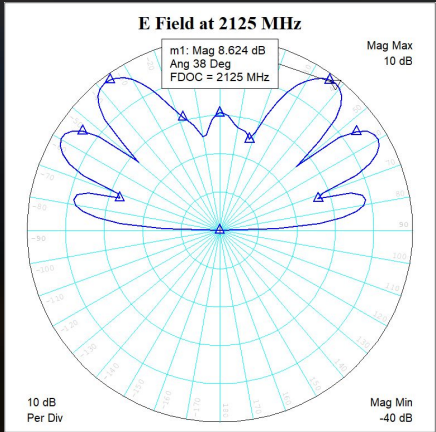
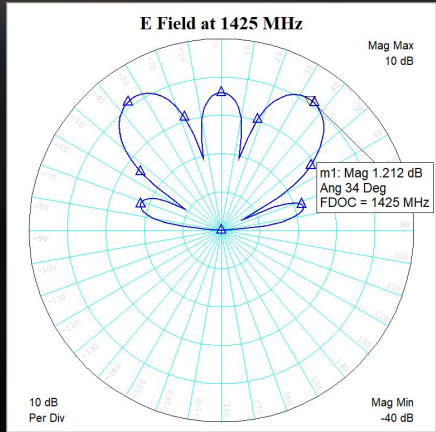
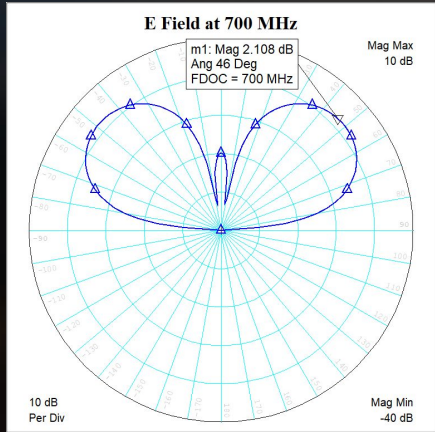
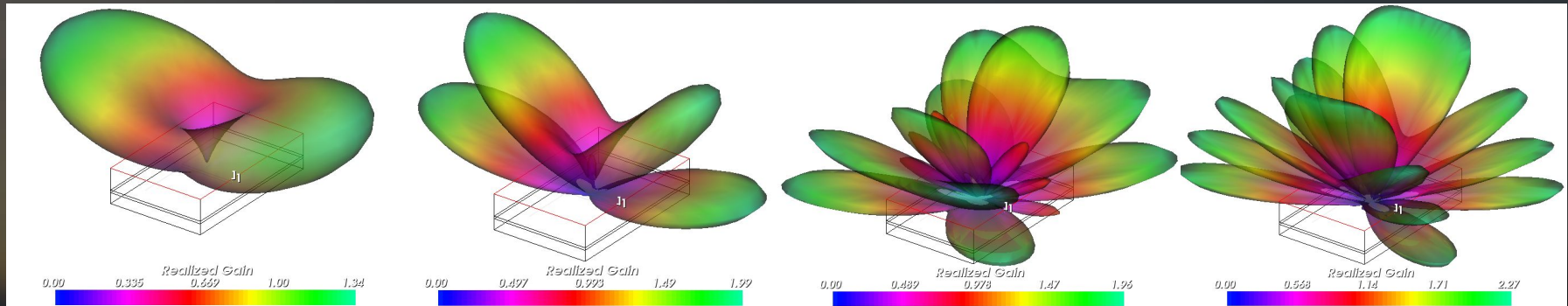
Height off Ground

- Ideal height of the doublet is $\lambda/2$ (of the lowest operating frequency).
- What if the antenna is $\lambda/4$ or $\lambda/8$ above the ground?



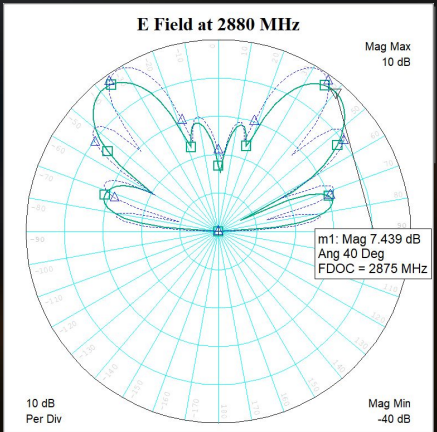
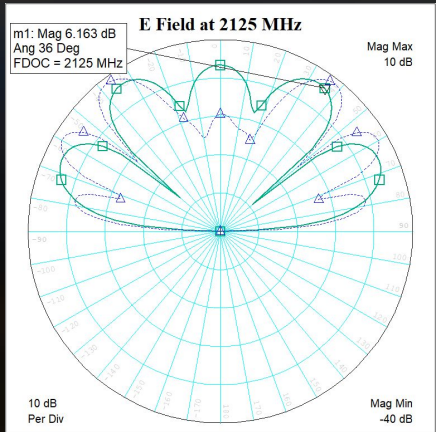
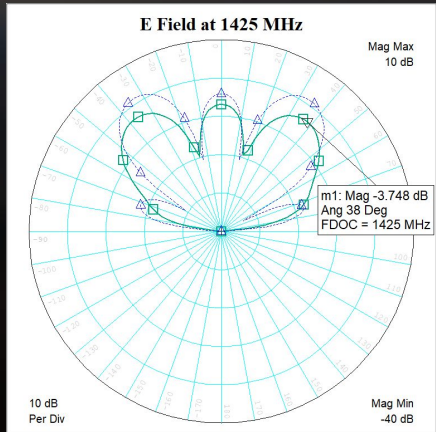
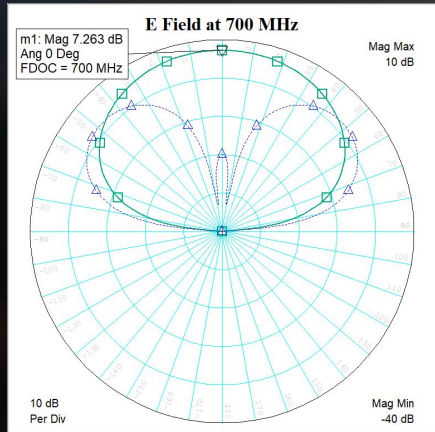
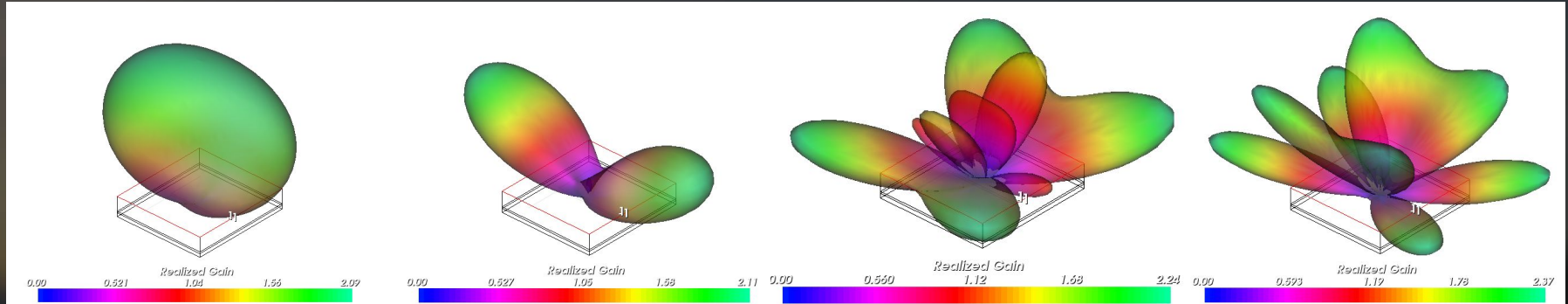
Height off Ground

$$h = \lambda/2$$



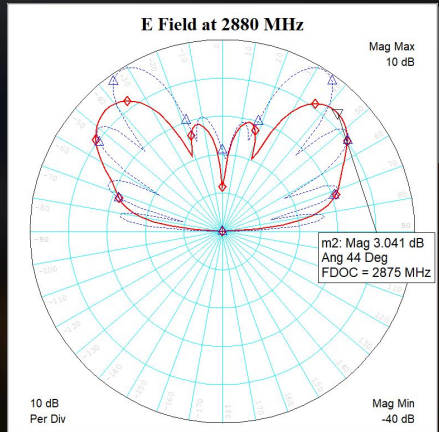
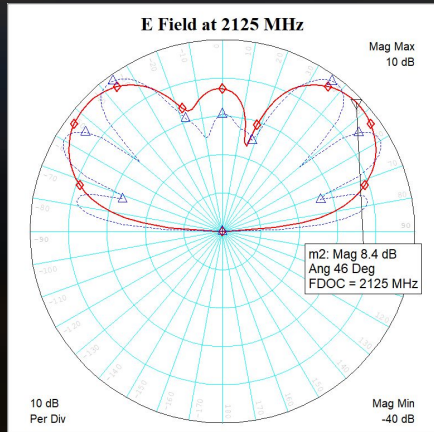
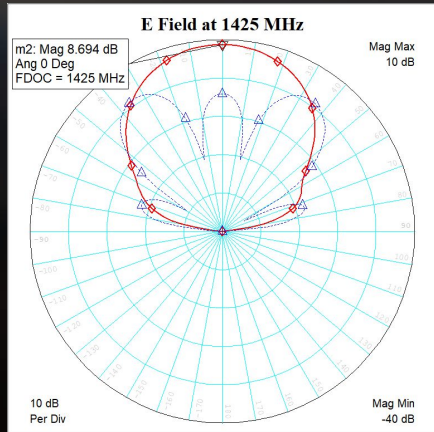
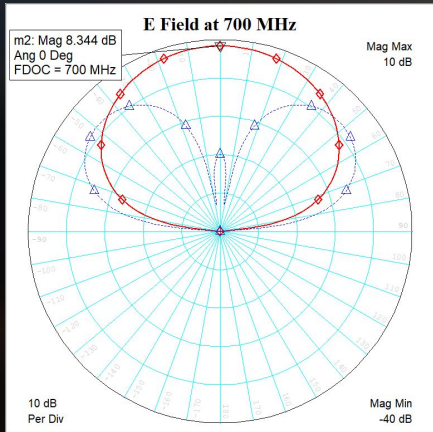
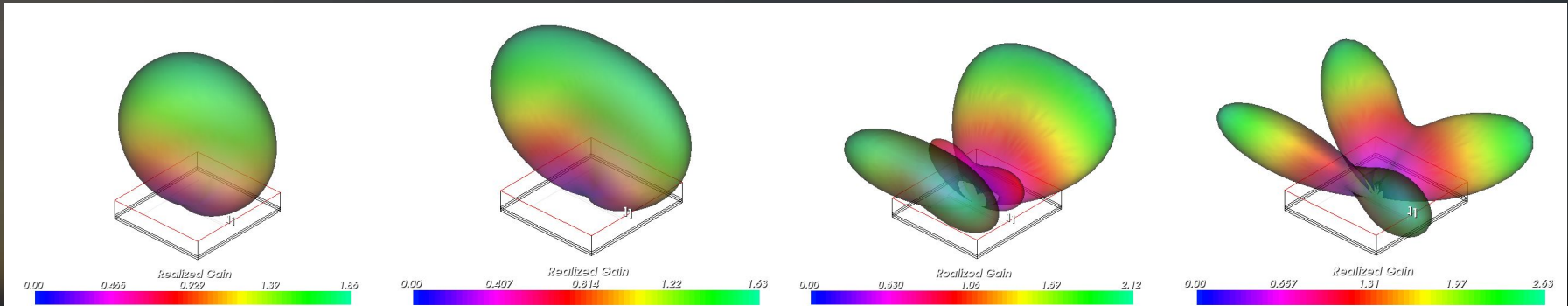
Height off Ground

$$h = \lambda/4$$

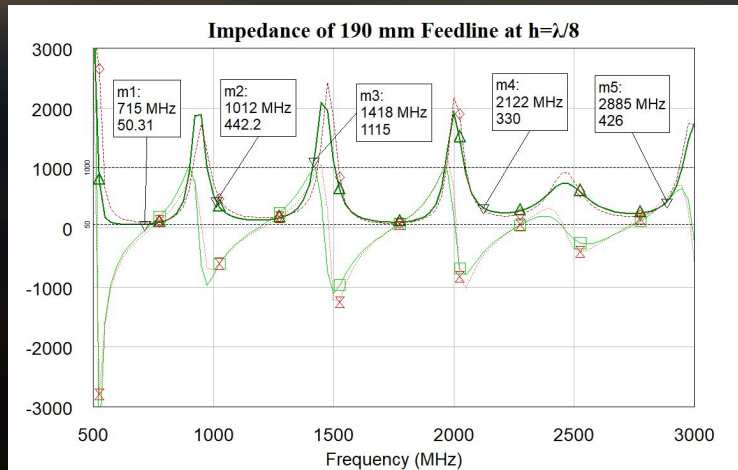
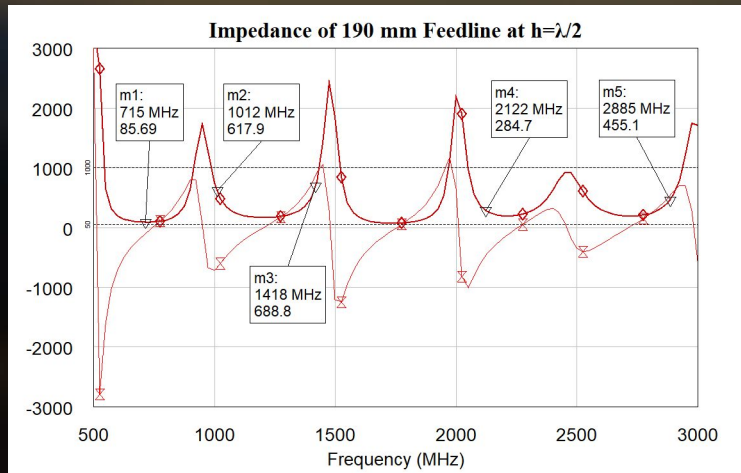
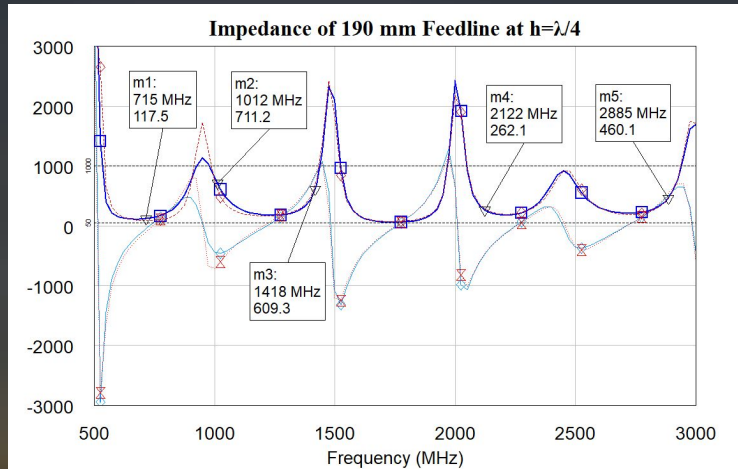


Height off Ground

$$h = \lambda/8$$



Height off Ground



\diamond Re($Z(1,1)$)
doublet_2.@190mm_feed

\times Im($Z(1,1)$)
doublet_2.@190mm_feed

\triangle Re($Z(1,1)$)
doublet_2.@107mm_feed

\square Im($Z(1,1)$)
doublet_2.@107mm_feed

\diamond Re($Z(1,1)$)
doublet_2.@160mm_feed

\times Im($Z(1,1)$)
doublet_2.@160mm_feed

Height off Ground

— Efficiency(1) $h=\lambda/2$
doublet_2.@190mm_feed

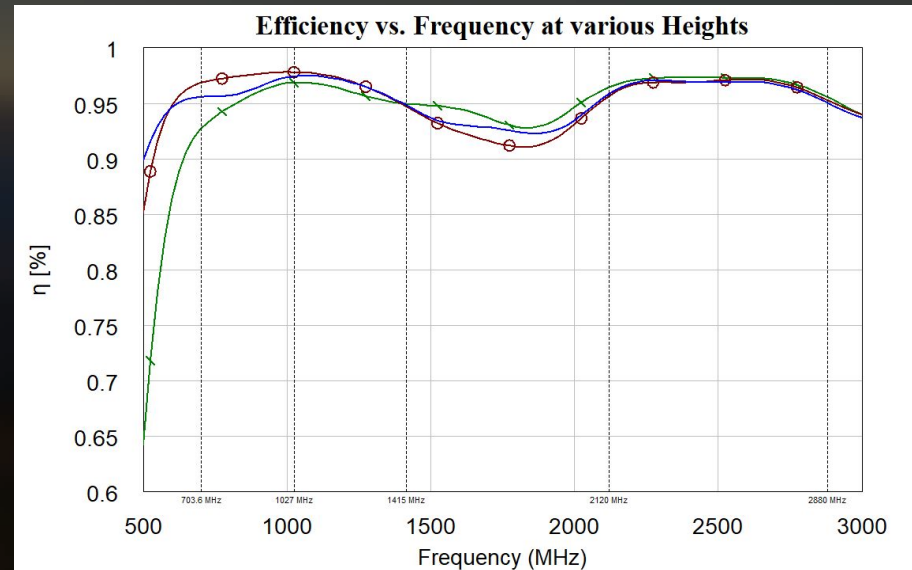
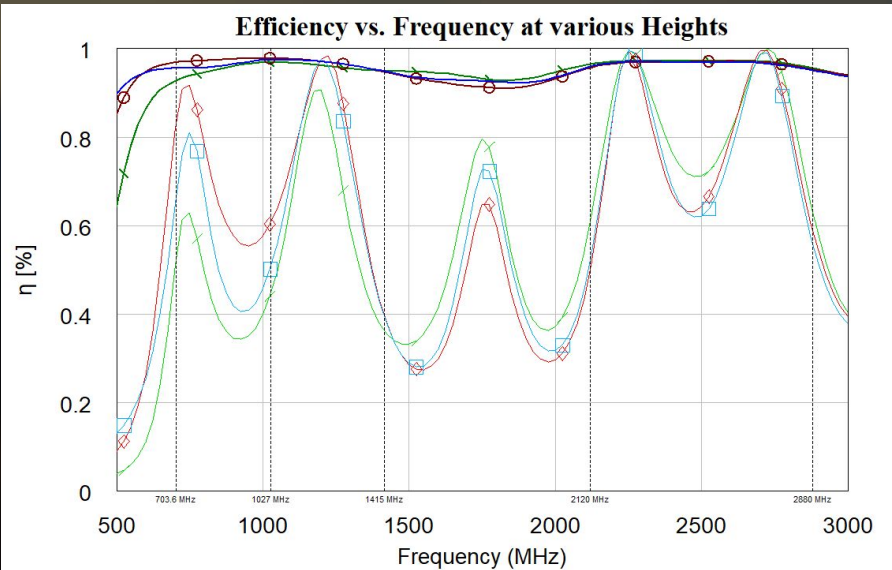
—○— Efficiency(1) $h=\lambda/4$
doublet_2.@1_4_lambda_h

—◇— Efficiency(1) $h=\lambda/8$
doublet_2.@1_8_lambda_h

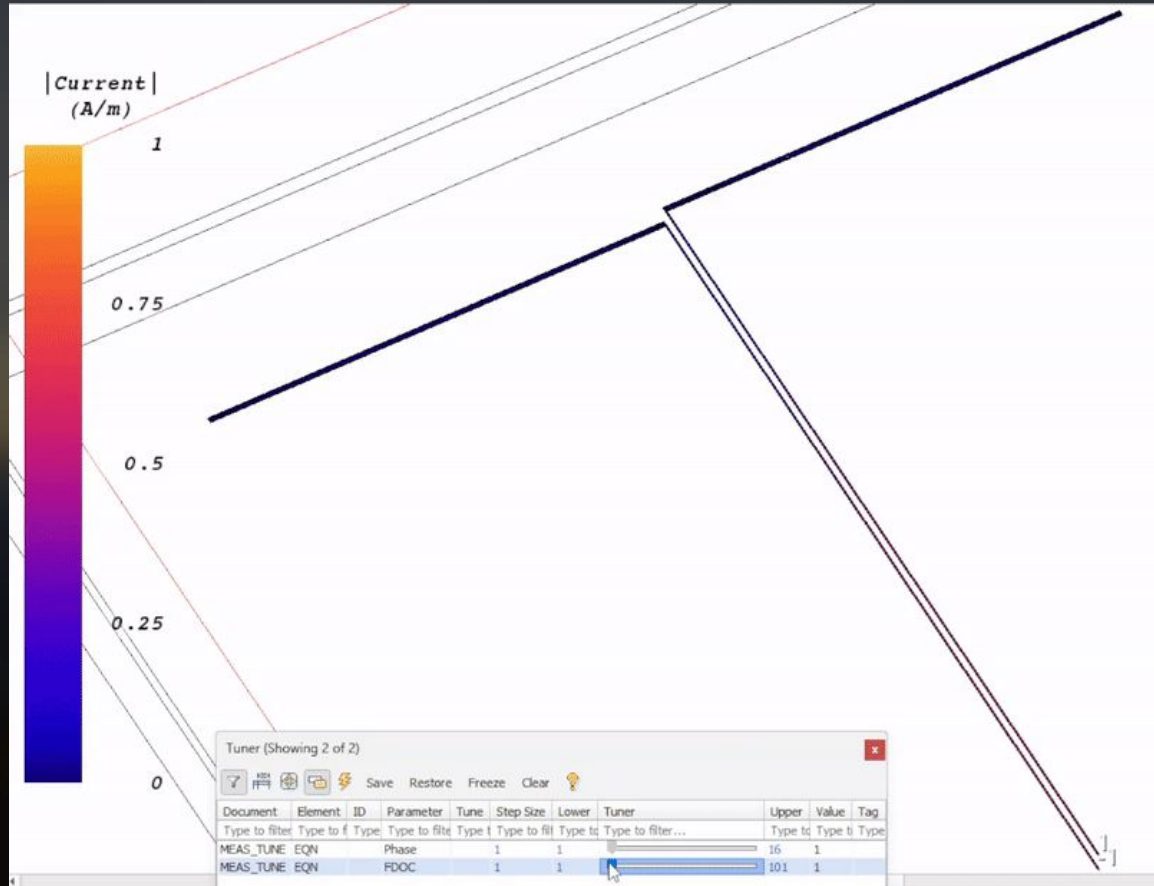
—□— Efficiency(2) $h=\lambda/2$
doublet_2.@190mm_feed

—◇— Efficiency(2) $h=\lambda/4$
doublet_2.@1_4_lambda_h

—◇— Efficiency(2) $h=\lambda/8$
doublet_2.@1_8_lambda_h



Currents

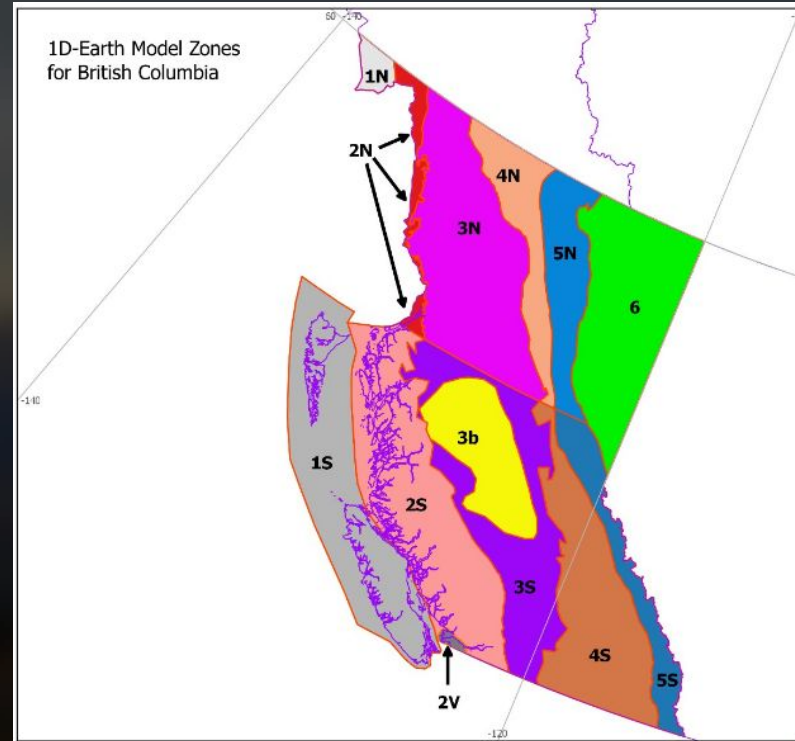


Earth Conductivity

- So far the ground plane was simulated as copper.
- In reality however the conductivity of the earth's crust varies widely by region.
- Two ground conductivities were tested.

Zone 3S - Intermontane Belt
(Valley / Rolling Hills)
Upper Crust
0-14 km
14 km thick
850 ohm.m [1.177e-03 S/m]

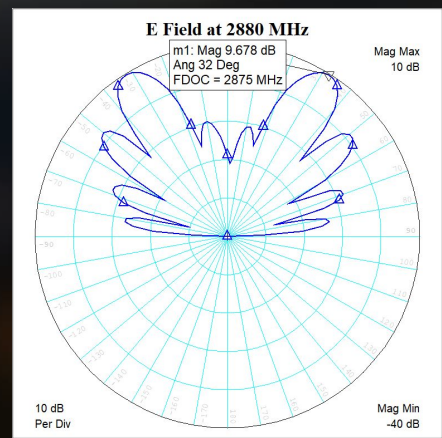
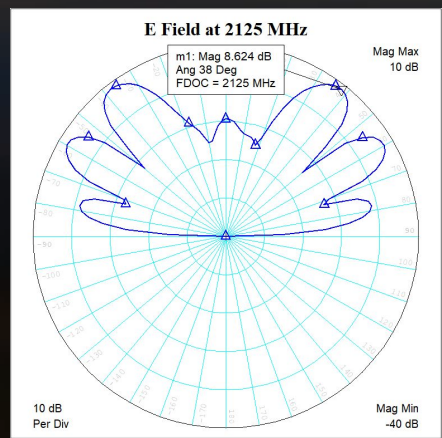
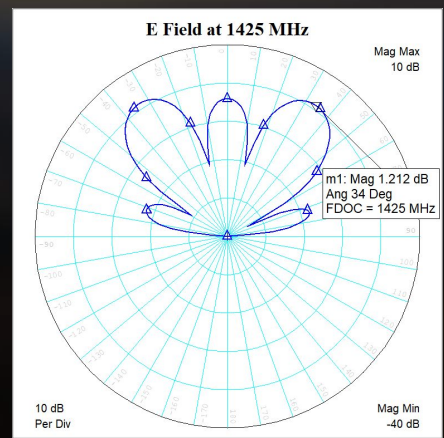
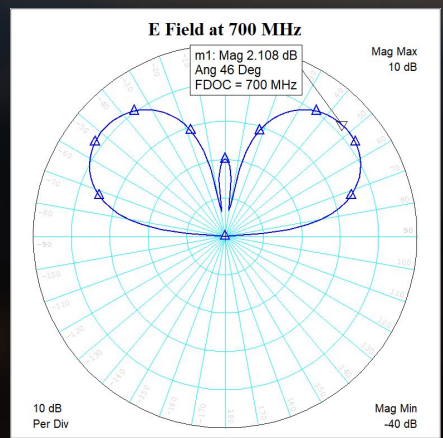
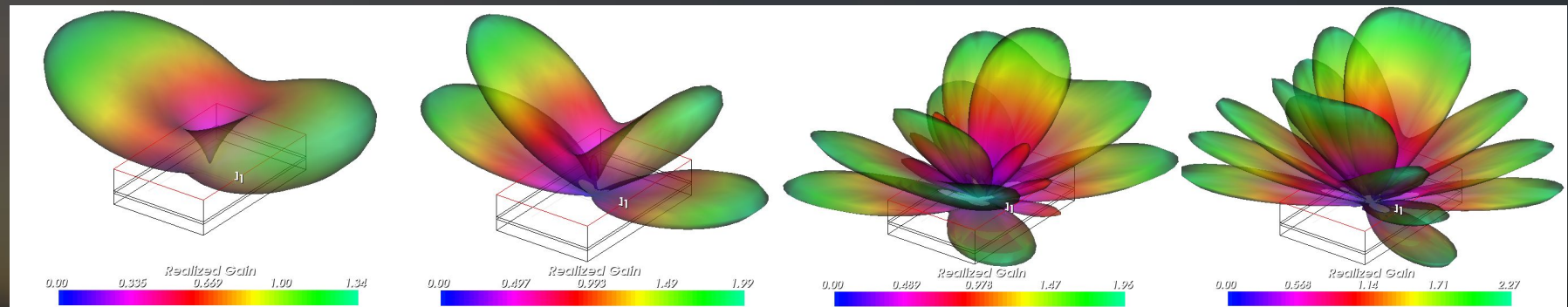
Zone 5S - Foreland Belt
(Mountainous)
Upper Crust
0-13 km
13 km thick
520 ohm.m [1.923e-03 S/m]



Earth Conductivity

Copper
Height of $\lambda/2$ with $\lambda/4$ Elements

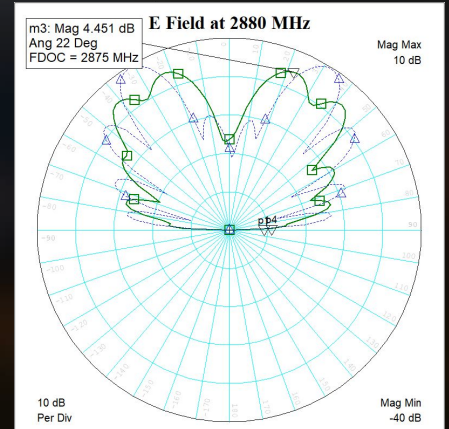
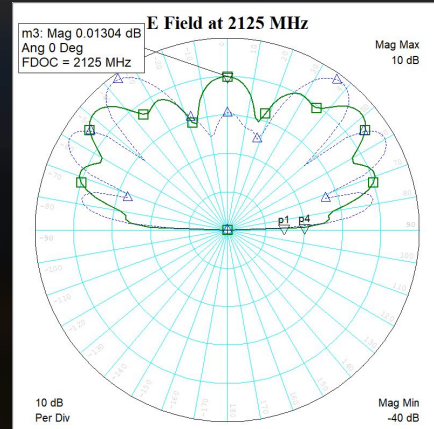
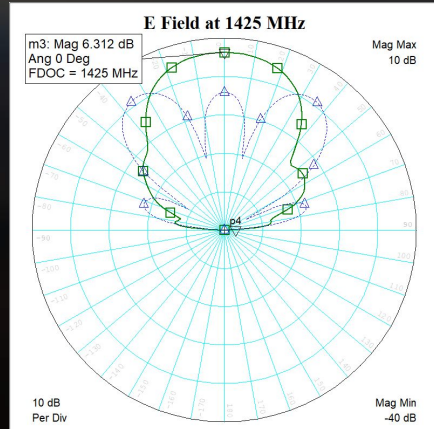
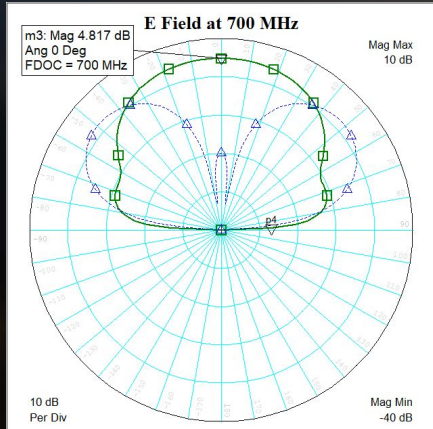
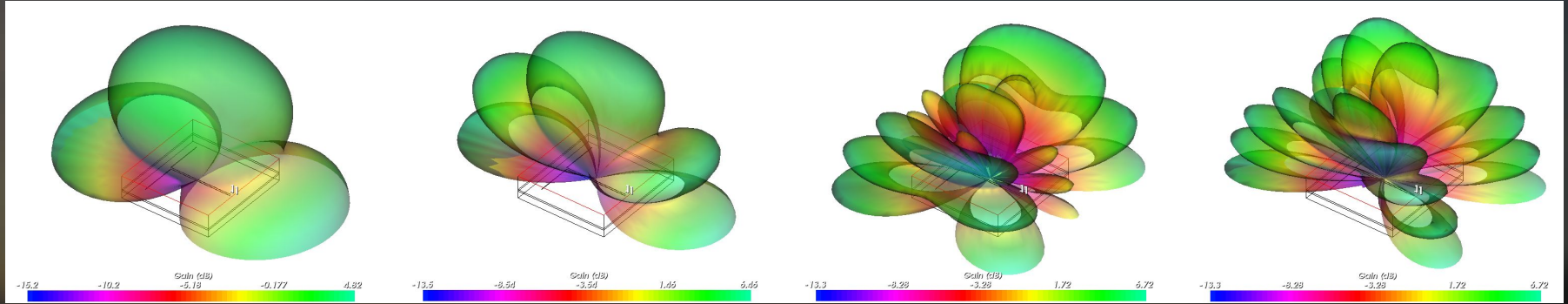
$\rho = 1.6e-8 \text{ ohm.m}$



Earth Conductivity

Intermontane Belt (Okanagan)

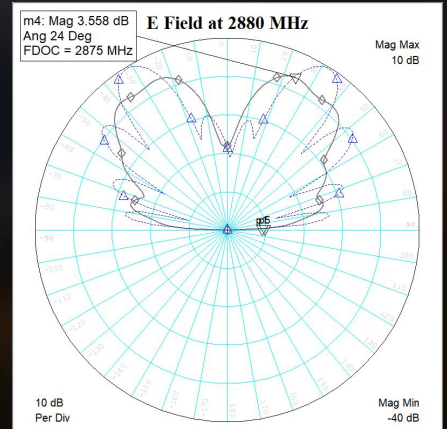
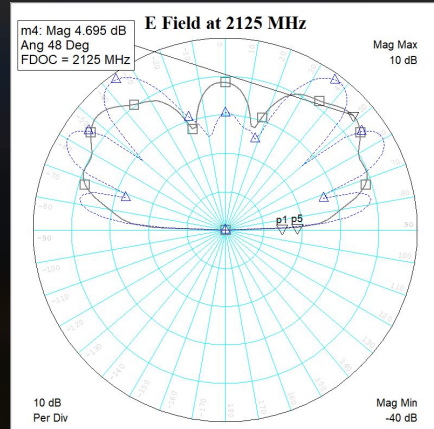
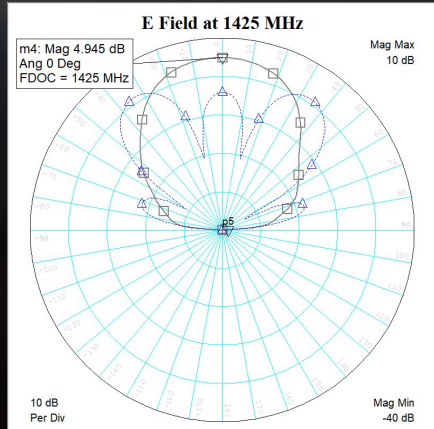
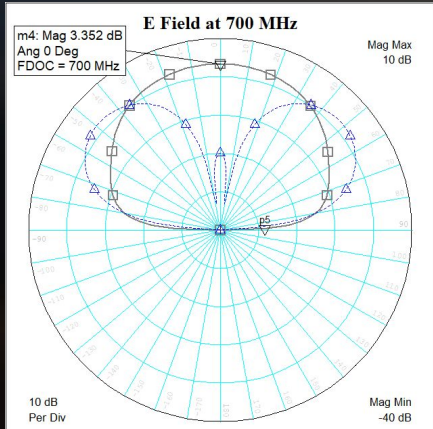
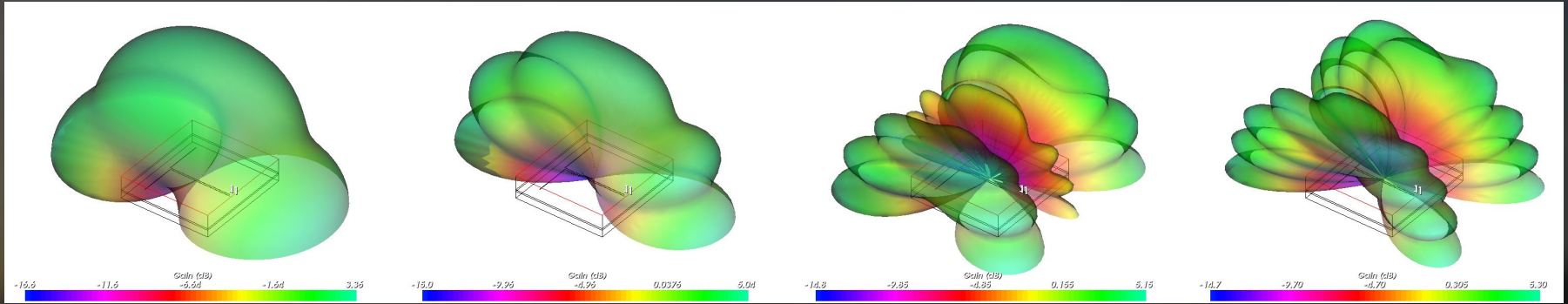
$$\rho = 850 \text{ ohm.m}$$



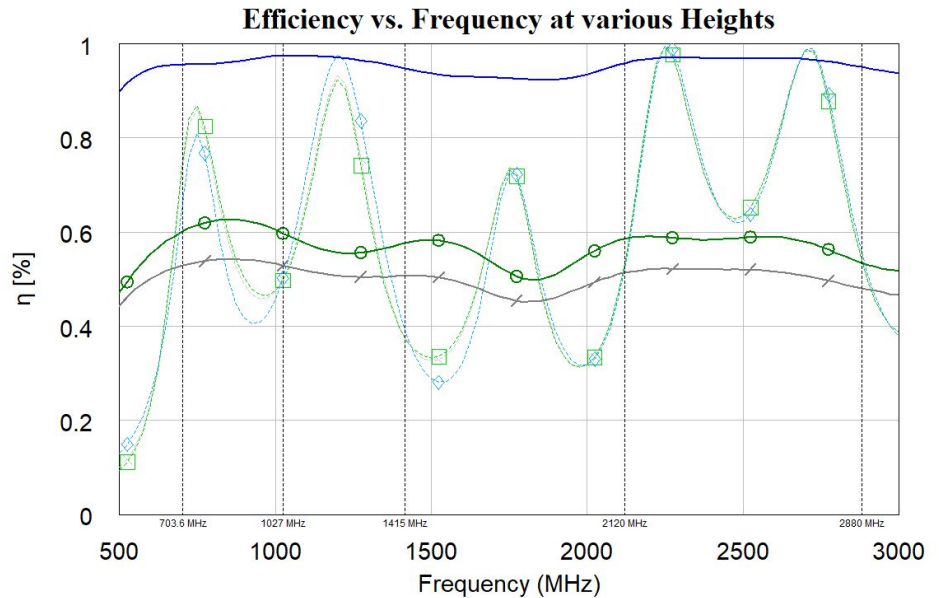
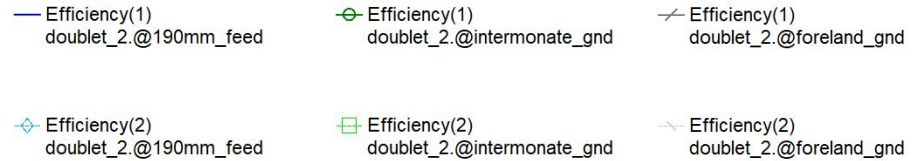
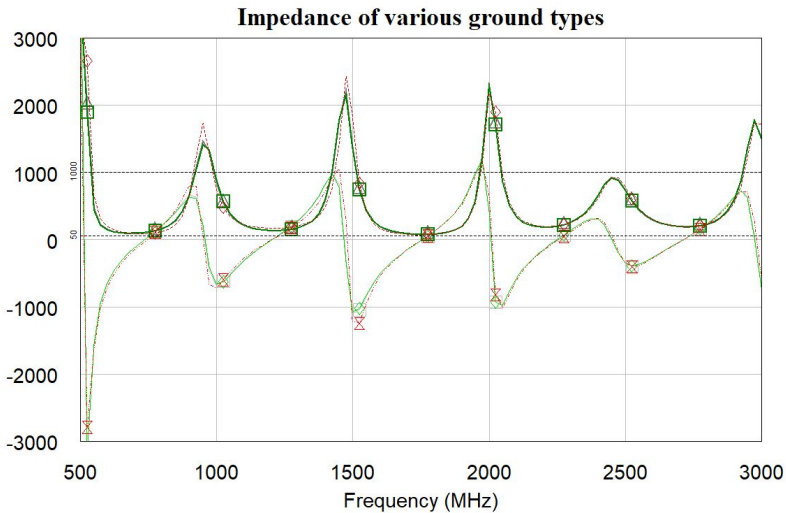
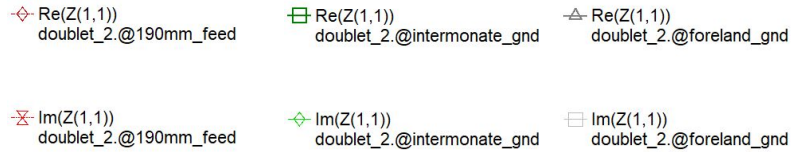
Earth Conductivity

Foreland Belt (Rockies)

$$\rho = 520 \text{ ohm.m}$$

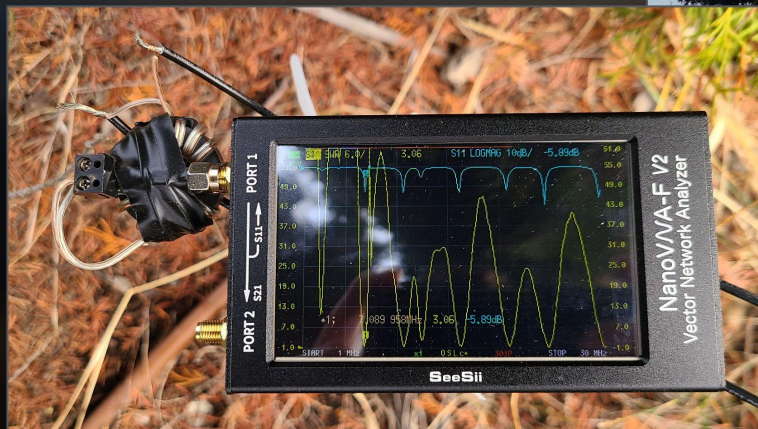


Earth Conductivity

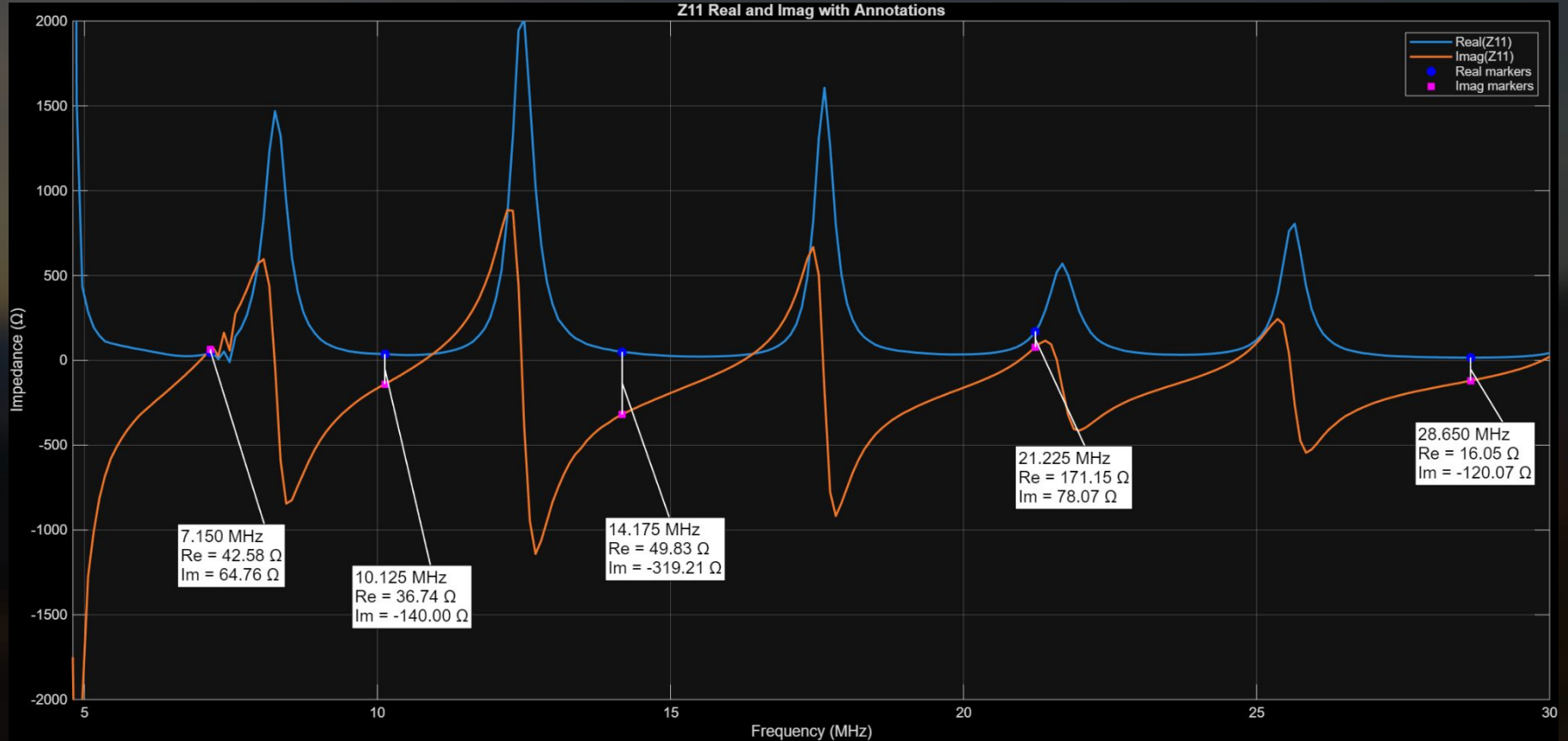


Homebrew Doublet

- 8.75m Tall (shy of $\lambda/4$)
- 10.71m elements
- 450 ohm feedline



Homebrew Doublet



Questions?

More on the antenna build over at

<http://mikebell.pages.dev/blog/2025/11/02/doublet-antenna/>

References & Resources

Slide	Figure Reference
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7	http://www.antentop.org/w4rnl.001/gup14.html
9	https://timesmicrowave.com/wp-content/uploads/2022/06/lmr-400-datasheet-1.pdf
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<https://webclass.org/k5ijb/antennas/1-All-Band-Doublet-W4RNL-Part%201-mw.pdf>

<https://www.silabs.com/documents/public/application-notes/an1275-imp-match-for-network-arch.pdf>

<https://hamwaves.com/ground/en/>

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